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ISOMAX: A Balloon-borne Instrument to Study Beryllium and Other Light Isotopes in the Cosmic Radiation

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ABSTRACT

The Isotope Magnet Experiment (ISOMAX), a balloon-borne magnetic rigidity spectrometer designed to measure the light isotopes of the cosmic radiation, is currently under construction. A major goal of the experiment is accurate measurement of the abundance of the radioactive isotope ^{10}Be up to relativistic energies (~ 4 GeV/nucleon). ISOMAX will make use of state-of-the-art instrument technology based on evolutionary development of detectors previously constructed by this collaboration. The ISOMAX detector complement will include high-resolution drift chambers for trajectory determination, a time-of-flight system, and a Cherenkov detector utilizing silica aerogel radiators. For rare isotopes, a large exposure factor is required to obtain statistically significant results. ISOMAX is specifically designed to take advantage of the emerging capability for long-duration balloon flights, with a two week dewar lifetime and low-power electronics. The first flight of ISOMAX is planned for 1995.

1. INTRODUCTION

Measurements of the isotopic composition of elements of the cosmic radiation provide significant constraints on cosmic ray source composition and cosmic ray transport and acceleration in the galaxy. In particular, accurate determination of the abundance of the radioactive secondary isotope ^{10}Be (half-life: 1.5×10^6 years) over an energy range extending well into the relativistic region is one of the most important measurements to be made in this field. Radioactive clock isotopes at higher energies survive longer because of relativistic time dilation. Extending measurements of a clock isotope to relativistic energies is thus equivalent to probing the age distribution of cosmic rays. However, it must be noted that interpretation of such measurements necessarily takes place in the context of a propagation model. In a leaky box model, the surviving fraction of a clock isotope reaching the earth is determined by the competition of the relativistically dilated lifetime with particle escape and interaction (see the review of Simpson and Garcia-Munoz, 1988, for a summary of experimental work on ^{10}Be and its interpretation). By contrast, for example, diffusion models of cosmic ray propagation allow for the possibility of regions of space with differing cosmic ray densities and a non-exponential age distribution (see, *e.g.*, Ginzburg *et al.*, 1980; Ptuskin and Soutoul, 1990). The predictions of diffusion models regarding the survival of ^{10}Be at relativistic energies differ markedly from the leaky box model prediction. Thus, precise measurements of ^{10}Be at several GeV/nucleon will put the leaky box model to a severe test.

Further insight into the cosmic ray source (CRS) composition itself can be provided by study of the light isotopes in the cosmic radiation. The primary elements C, N, and O are of particular interest because of their role in stellar nucleosythesis and chemical evolution. For these species, some significant differences have been discovered between solar system composition and derived CRS values. The recent measurement and determination of the CRS ^{18}O/^{16}O ratio by Gibner *et al.* (1992)

reveals an enhancement over its solar system value. The CRS $^{14}N/^{16}O$ ratio is also not easily reconciled with the solar value (Krombel and Wiedenbeck, 1988).

2. INSTRUMENT DESCRIPTION

2.1 Overall Design: The detectors in ISOMAX are "low-risk" in that they are evolutionary developments of those already used on the IMAX experiment (Mitchell *et al.*, 1993, and references therein). Additionally, the dewar and magnet design are within the capability of commercial fabricators. From its inception, the instrument has been designed to exploit the emerging capability for long duration balloon flight. Low-power electronics being developed for the drift chambers, logic, and TOF TDCs are expected to save a factor of 5 in power consumption compared to the commercial units previously used. New low-power VLSI analog electronics resulting from satellite program technology transfer will also be incorporated in the instrument.

The ISOMAX instrument is shown schematically in Figure 1. The main components are a two-coil superconducting magnet, with a long-lifetime dewar, two velocity measuring systems [a time-of-flight system (T1, T2, T3) and a Cherenkov counter (CK)], and a hex-cell drift chamber tracking system. The instrument has a large geometry factor to facilitate study of rare isotopes such as ^{10}Be. Table 1 displays the baseline instrument characteristics of ISOMAX as configured for an initial 40-hour flight. Comments on the several components of the instrument follow.

TABLE 1. ISOMAX Baseline Instrument Characteristics

Overall Performance:	
Average field integral:	$\langle Bxdl \rangle = 0.78$ T-m
Maximum detectable rigidity	$\langle MDR \rangle = 920$ GV
Geometry factor:	$A\Omega = 550\ cm^2$ sr
Dewar	
Lifetime :	> 14 days
Magnet	
Type:	Superconducting, quasi-Helmholtz
Coil dimensions:	60 cm diameter, 66 cm separation
Warm Bore:	60 cm x 60 cm
Field at center of bore:	1.5 Tesla
Tracking:	
Type:	Drift Chamber; hexagonal cathode wire array 22 planes (14 X, 8 Y), CO_2 gas
Dimensions:	Maximum plane separation 1.2 m
Resolution	< 100 μm
Time of Flight System	
Type:	Three multi-panel plastic scintillator arrays
System 1 (T1,T3)	2 m flight path, 50 psec resolution for Z=4
System 2 (T1,T2)	1.7 m flight path, 60 psec resolution for Z=4
Cherenkov Detector	
Type:	Light integration
Radiator:	Silica aerogel radiator, n =1.15, 9 cm thick
Performance:	26 photoelectrons (Z=1, β=1)
Instrument Weights	
Launch ready:	1350 kg (2980 lbs), includes 190 kg cryogen and batteries

2.2 The magnet and dewar: There are several constraints on the design of the magnet and dewar. First, the requirement to measure rare light isotopes in the few GeV/nucleon range dictates that the dewar lifetime must allow flight times of at least 10 days duration. Second, the magnet must provide sufficient bending power to give excellent mass resolution both for beryllium up to 4 GeV/nucleon and for higher charge isotopes at low energies ($\beta \ll 1$) where multiple scattering becomes a significant contribution to mass resolution.

2.3 The tracking system: ISOMAX will use a multi-cell drift chamber system based on that used in the recent IMAX balloon flight (Hof *et al.*, 1993 and Menn *et* *al.*, 1993) which obtained position resolution of better than 100 μm over most of the drift path. The ISOMAX tracking system will consist of three chambers: one located in the magnet bore, one above the magnet, and the other below. All three chambers will be tied together by a common structure to insure that the relative alignment between the chambers is constant.

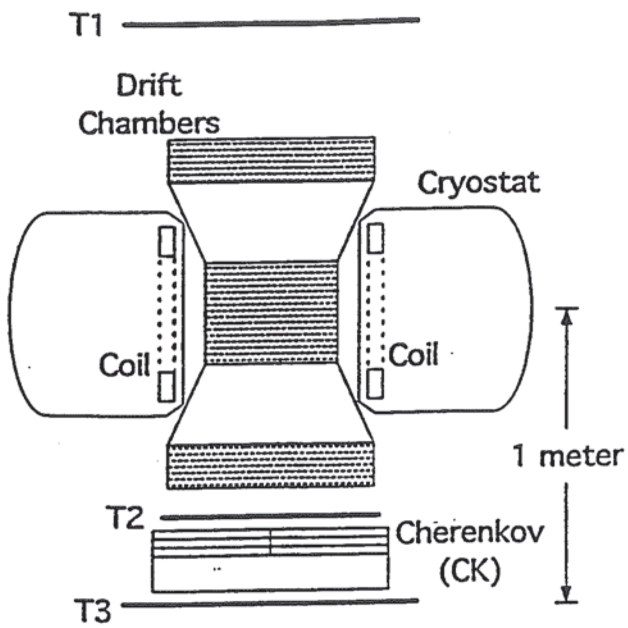

Figure 1

2.4 The TOF detector: A high-performance TOF system will determine particle velocity and provide the first level event trigger and measurement of charge. The TOF system will consist of three planes of fast plastic scintillator composing two semi-independent systems. Initial analysis of the IMAX flight data with no amplitude corrections shows a flight-time resolution of 130 picoseconds for protons (Mitchell *et al.*, 1993). For charges (Z) greater than one, it is expected that the intrinsic timing should improve by almost a factor of ~1/Z. We expect TOF resolution approaching 75 picoseconds for He and 50 picoseconds for Be in ISOMAX, sufficient to resolve Be isotoptes up to ~ 1 GeV/nucleon.

2.5 The Cherenkov counter: ISOMAX will use a diffusive light collection box with silica aerogel radiators. Methods for storing, machining, mounting and optimizing the light yield from these materials have been developed over the last decade; these techniques were used to construct two Cherenkov counters for the IMAX experiment (Labrador *et al.*, 1993). For the first flight of ISOMAX, an aerogel radiator with an index of n=1.15 was selected. Isotopes of the elements up to and including oxygen will be well-resolved between 1.0 and 1.5 GeV/nucleon. The photoelectron yield in Table 1 is conservatively scaled from the measured yield of the C3 Cherenkov counter from IMAX, taking into account the relative photocathode and reflective surface areas and the differing indices of refraction.

3. FLIGHT PLANS AND EXPECTED INSTRUMENT PERFORMANCE

Fabrication of ISOMAX will begin in April 1993, and a first flight is planned for the summer of 1995 from northern Canada. In a turnaround flight from Lynn Lake, Manitoba, a duration of 40 hours at float should be obtainable. When configured as above, the observations will cover an energy range from geomagnetic cutoff to about 1.5 GeV/nucleon for the isotopes of lithium through oxygen with a mass resolution better than 0.25 amu.

Within two years of the initial flight, we plan to carry out a long-duration flight of ISOMAX to extend the measurement of beryllium and other light isotopes to higher energies. A Cherenkov aerogel index which allows measurement above 2 GeV/nucleon will be selected, with the choice depending on results of the first flight and our assessment of the then current capabilities of long-duration ballooning.

The expected performance of the ISOMAX instrument has been evaluated using both Monte Carlo and analytic simulations. Figure 2 shows beryllium mass histograms for two representative energy ranges as generated by the the Monte Carlo program using the instrumental characteristics in Table 1. Panel (a) uses only the TOF system to determine velocity for Be and covers the energy range from 200 to 500 MeV/nucleon. Panel (b) displays only those Be nuclei having a Cherenkov signal less than 0.46 times the β=1 response. The energy range covered is 960-1500 MeV/nucleon.

We have estimated the isotope yields from a 2-day Canadian flight of ISOMAX assuming: (1) a 1995 flight (near solar minimum conditions); (2) 40 hours at float altitude, with 5 gm-cm^{-2} overburden (secondary production and fragmentation losses in the atmosphere are included). Losses in the instrument have also been taken into account. The rarest isotope in this charge range is ^{10}Be. As can be seen in Table 2, ISOMAX will yield sufficient Be statistics to provide data in several energy bins up to 1.5 GeV/nucleon. Table 2 also displays the number of beryllium isotopes expected for a 10-day long duration flight using an n = 1.045 aerogel radiator sensitive in the 2.3-2.9 GeV/nucleon range.

Based on our simulations, the ISOMAX instrument will be capable of measuring (Z≤8) isotopes up to about 4 GeV/nucleon, and other light isotopes (through silicon) to somewhat lower energies with significantly improved statistical accuracy over previous experiments.

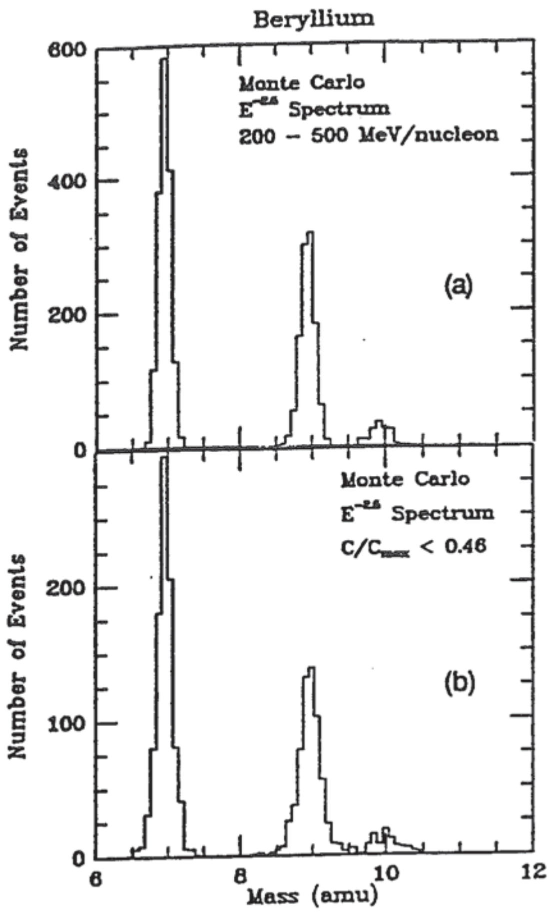

Figure 2

TABLE 2
Expected Yield (Number of Events)

Element	Z	A	Canada 40 hr. flight ≤1 GeV/n	Canada 40 hr. flight 1-1.5 GeV/n	Long Duration 10 day flight ≤1 GeV/n	Long Duration 10 day flight 2.3-2.9 GeV/n
Be	4	7	1600	400	9500	880
		9	1100	270	6400	590
		10	190	75	1100	250

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